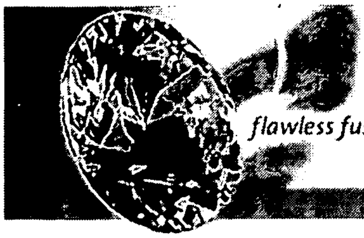


SIFAM FIBRE OPTICS

Subminiature Tap Coupler

The Subminiature Tap Coupler provides low loss splitting and monitoring in an ultra-short 32mm length package. Designed for space constrained applications, the product is manufactured using ∅80μm cladding fibre. This enables low fibre bend radius within modules without compromising mechanical integrity.

SIFAM proprietary manufacturing technology provides uniquely low excess loss and wavelength dependence, along with low polarisation and temperature dependence for both signal and tap ports.

Standard wavelengths of operation are the C, L, C+L or S bands, for fibre amplifier applications. However many other wavelengths are available for requirements such as sensing, fibre lasers and fibre gyros. Do not hesitate to contact us with your specific requirements.

Reliability is assured through qualification to Telcordia GR-1221.

Key Features:

- 32mm package length
- ∅80μm cladding fibre
- 1/99 to 50/50 coupling ratio
- Ultra low typical <0.05dB excess loss
- High power handling
- Proven reliability

Applications:

- Miniature Optical Amplifiers
- Miniature Modules
- Fibre Gyros
- Fibre Lasers
- Sensors

Compliance:

- Telcordia GR-1221

SIFAM Fibre Optics Ltd
Broomhill Way, Torquay
Devon TQ2 7QL
England

Tel: +44(0) 1803 407784
Fax: +44(0) 1803 407786
sales@sifamfo.com
www.sifamfo.com

Certificate No. 0962231

Optical Specifications

C or L band

		Signal Path					Tap Path				
Coupling Ratio	Grade	Insertion Loss 1,2 (dB)		WDL3 (dB)	PDL4 (dB)	TDL5 (dB)	Insertion Loss 1,2 (dB)		WDL3 (dB)	PDL4 (dB)	TDL5 (dB)
Example6		Min	Max	Max	Max	Max	Min	Max	Max	Max	Max
1%	A		0.18	0.05	0.05	0.02	17.6	22.4	0.35	0.25	0.20
2%	A		0.20	0.05	0.05	0.02	15.8	18.2	0.30	0.20	0.15
3%	A		0.28	0.05	0.05	0.04	13.8	17.0	0.26	0.20	0.15
5%	A		0.40	0.05	0.05	0.08	11.9	14.4	0.20	0.20	0.15
10%	A		0.70	0.06	0.06	0.08	9.2	11.2	0.18	0.15	0.13
50%	A	2.70	3.40	0.15	0.10	0.10	2.7	3.4	0.15	0.10	0.10

C+L or S band

		Signal Path					Tap Path				
Coupling Ratio6	Grade	Insertion Loss 1,2 (dB)		WDL3 (dB)	PDL4 (dB)	TDL5 (dB)	Insertion Loss 1,2 (dB)		WDL3 (dB)	PDL4 (dB)	TDL5 (dB)
Example6		Min	Max	Max	Max	Max	Min	Max	Max	Max	Max
1%	A		0.18	0.06	0.05	0.02	17.4	23.0	1.20	0.25	0.20
2%	A		0.20	0.07	0.05	0.02	15.2	20.0	1.00	0.20	0.15
3%	A		0.28	0.07	0.05	0.04	13.7	17.4	0.90	0.20	0.15
5%	A		0.40	0.08	0.05	0.08	11.8	14.8	0.80	0.20	0.15
10%	A		0.70	0.09	0.06	0.08	9.0	11.4	0.60	0.15	0.13
50%	A	2.60	3.50	0.40	0.10	0.10	2.6	3.5	0.40	0.10	0.10

1. Insertion loss over operating wavelength range (not including PDL and TDL)
2. In 2x2 couplers insertion loss is not specified for launch through second input port P4 (coloured blue)
3. Change in insertion loss over the operating wavelength range
4. Change in insertion loss over all input polarisation states at band centre wavelength
5. Change in insertion loss from -5 to 75°C
6. Any coupling ratio available – contact SIFAM for specification of coupling ratios not listed.

Parameter		Specification	Unit
Operating Wavelength Range	C Band	1528-1563	nm
	L Band	1570-1605	nm
	C+L band	1528-1605	nm
	S band	1425-1500	nm
Return Loss/Directivity1		55	dB
Pigtail Tensile Load		5	N
Optical power handling		4	W
Operating Temperature Range		-40 to +75 / -40 to +85	°C
Environmental Qualification		Telcordia GR 1221	

1. Return loss is the ratio of power launched to power reflected for port P1. Directivity for the 2x2 component is the ratio of power launched to P1 to the power reflected to P4.

SIFAM Fibre Optics Ltd
Broomhill Way, Torquay
Devon TQ2 7QL
England

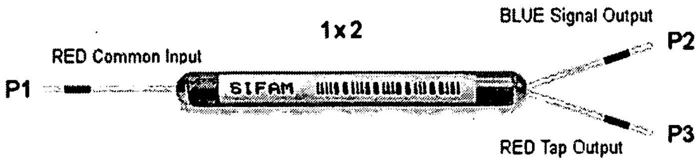
Tel: +44(0) 1803 407784
Fax: +44(0) 1803 407786
sales@sifamfo.com
www.sifamfo.com

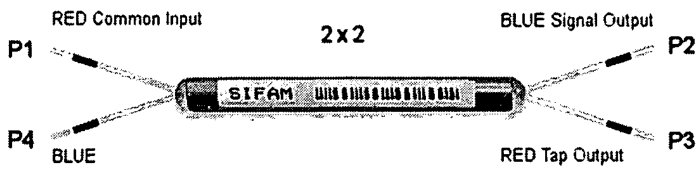
SIFAM FIBRE OPTICS

Housing Option

Housing Code	Description	1x2, 2x2 Dimensions (mm)	Pigtail
1	Subminiature	3.0 (∅) x 32 (L)	Primary-coated fibre, 80µm cladding

Configuration





Ordering Code Information

Example: FFC-C211AB310 (C Band, 2% tap, subminiature housing, A grade, ϕ80µm cladding fibre, 1m pigtails, no connector)

F F C - ☐ ☐ 1 ☐ A B ☐ ☐ 0

Code	Passband
C	C band
L	L band
1	C+L band
S	S band

Code	Coupling Ratio[2]
1	1%
2	2%
3	3%
5	5%
A	10%
K	50%

Code	Housing
1	Subminiature

Code	Port Configuration
1	1x2
2	2x2

Code	Grade
A	Grade A

Code	Fibre Type
3	∅80µm cladding fibre
8	∅80µm cladding high NA fibre

Code	Pigtail Length[1]
0	0.5m
1	1m

Code	Connector
0	None

1. Minimum pigtail length. Further pigtail lengths available on request.
2. Any coupling ratio available – contact SIFAM for specification and ordering codes of coupling ratios not listed.

SIFAM Fibre Optics Ltd
Broomhill Way, Torquay
Devon TQ2 7QL
England

Tel: +44(0) 1803 407784
Fax: +44(0) 1803 407786
sales@sifamfo.com
www.sifamfo.com

Certificate No. 0962231

ATI Optique

Tap coupler on PM fiber

ATI PM couplers (Polarization maintaining fiber) are available either with Panda or Bow Tie fiber .
These taps couplers are available in different packaging options.
PM connectors can also be mounted on these devices .

Optical specifications (@ 1550 nm)

Configuration : 1x2

Coupling ratio : 95/5

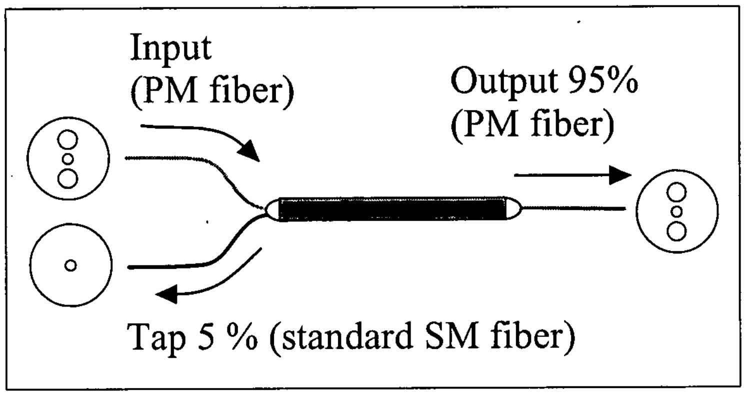
Excess loss : 0.8 dB maximum
0.5 dB typical

PER (20°C) : > 20 dB

Optical return loss : > 50 dB

Operating temperature : 0 to + 50°C

Bandpass : 1480 - 1625 nm



Packaging options

Bare fiber option : Invar tube package type 71 : length 40 mm , diam 3 mm
Lead length : 50 cms

900µ loose tube : Invar tube package type 76 : Length 66 mm , diam 3.9 mm
Lead length : 50 cms

Options : PM connectors : FC or SC style , PC or APC termination

Part numbers

Panda Fiber : CPM.PA.15.05.YY.ZZ.1
Bow Tie fiber : CPM.BO.15.05.YY.ZZ.1

YY : package : bare fiber : 71 , 900µ : 76
ZZ : connector style : FC/PC : 16 , FC/APC : 17 , SC/PC : 12 , SC/APC : 13

TEL : + 33 1 69 36 64 00

ATI Optique Division of ATI electronique
6 Rue Jean-Mermoz , Z.A. de St Guenault 91080 Courcouronnes FRANCE
Fax : + 33 1 64 97 14 84

Ultra-Low PDL Fused Tap Coupler (1310, S, C, L band)

Product Description

Features

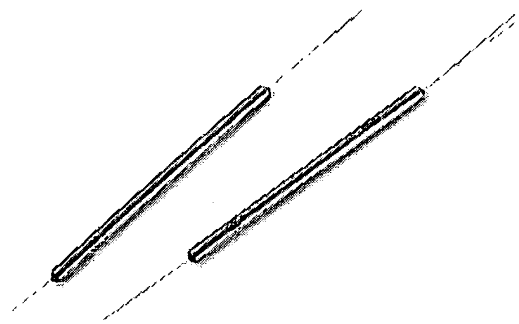
- Wavelength Independent
- Low Insertion Loss and PDL
- High Power Handling
- Guaranteed Reliability

Ultra-Low PDL Fused Tap Coupler (1310, S, C, L band)

The Oplink LPTC (1x2 and 2x2) coupler series feature exceptionally low polarization dependent loss on both signal and tap ports as well as excellent uniformity and low excess loss. They are available with various tap ratios, wavelength ranges, fiber types, and connector options. All devices are shown to be able to handle high optical power up to 4W and are tested according to industry standard procedures. Reliability is guaranteed through stringent tests to fully meet Telcordia GR-1221 requirements.

Applications

- Signal monitoring in EDFA
- CATV
- Local Area Networks
- Testing Instruments



Oplink Fiber Optic Product Lines

- Amplifier Components
- Amplifier Modules
- DWDMs
- Switching/Routing/ Signal Conditioning

Performance Specifications

Parameter		1310nm	S band	C band	L band
Wavelength Range	nm	1270~1350	1420~1500	1530~1565	1570~1605
Fiber type		Corning SMF-28			
Insertion loss[1]		See Insertion Loss Table I, II			
Return loss	min	55 dB			
Directivity	min	55 dB			
Temperature dependent loss[2]	max	Signal Path: 0.02~0.10dB, Tap Path: 0.10~0.20 dB			
Optical power handling	max	4 W			
Operating temperature range[3]		-40 to 75 °C			
Storage temperature range		-40 to 85 °C			
Package Dimension [4]		P1: 250mm cladding fiber		(Ø)3.0 x (L)47 mm	
		P2: 900mm loose tub		(Ø)3.0 x (L)60 mm	
		P3: 3mm cable		(L)96 x(W)12 x (H)6.4mm	
Qualifications		Telcordia GR-1221			

1. Values are referenced without connector loss.
2. Change in insertion loss from -5 to 75°C. Values are depended on coupling ratio, for 99/1 couplerTemperature Dependent Loss (TDL) ~0.02/0.20dB. As tap ratio increase, TDL decreases for tap path, while increases for signal path. All TDL is specified from -5 to75°C
3. Operating temperature range changes to -5 to 75°C in P2, P3 package and all package with connectors
4. The mechanical tolerance should be +/- 0.2 mm on all package dimensions unless otherwise custom specified.

OPLINK COMMUNICATIONS

Ultra-Low PDL Fused Tap Coupler (1310, S, C, L band)

Insertion Loss Tables

Insertion Loss (IL) I : C or L band coupler

Coupling Ratio	P Grade						A Grade					
	IL[1] (dB)		WDL[2] (dB)		PDL[3] (dB)		IL[1] (dB)		WDL[2] (dB)		PDL[3] (dB)	
	Signal	Tap	Signal	Tap	Signal	Tap	Signal	Tap	Signal	Tap	Signal	Tap
99/1	≤0.18	19.0-21.0	≤0.05	≤0.45	≤0.03	≤0.03	≤0.20	17.7-21.5	≤0.05	≤0.55	≤0.05	≤0.05
98/2	≤0.25	16.4-18.4	≤0.06	≤0.40	≤0.03	≤0.03	≤0.30	16.0-19.4	≤0.07	≤0.45	≤0.05	≤0.05
97/3	≤0.30	14.6-16.2	≤0.07	≤0.30	≤0.03	≤0.03	≤0.35	14.0-16.8	≤0.09	≤0.40	≤0.05	≤0.05
95/5	≤0.35	12.4-13.8	≤0.08	≤0.25	≤0.03	≤0.03	≤0.40	12.0-14.4	≤0.11	≤0.30	≤0.05	≤0.05
90/10	≤0.60	9.60-10.8	≤0.10	≤0.22	≤0.03	≤0.03	≤0.65	9.20-11.2	≤0.13	≤0.26	≤0.05	≤0.05
85/15	≤0.85	7.80-8.80	≤0.11	≤0.20	≤0.03	≤0.03	≤0.90	7.5-9.0	≤0.14	≤0.25	≤0.05	≤0.05
80/20	≤1.15	6.60-7.60	≤0.11	≤0.18	≤0.03	≤0.03	≤1.15	6.4-8.0	≤0.16	≤0.23	≤0.05	≤0.05
75/25	≤1.35	5.75-6.50	≤0.11	≤0.17	≤0.03	≤0.03	≤1.44	5.6-6.7	≤0.16	≤0.21	≤0.05	≤0.05
70/30	≤1.75	5.00-5.50	≤0.11	≤0.16	≤0.03	≤0.03	≤1.82	4.9-5.8	≤0.16	≤0.20	≤0.05	≤0.05
65/35	≤2.10	4.40-4.90	≤0.12	≤0.15	≤0.03	≤0.03	≤2.15	4.3-5.0	≤0.16	≤0.19	≤0.05	≤0.05
60/40	≤2.50	3.95-4.30	≤0.13	≤0.15	≤0.03	≤0.03	≤2.60	3.7-4.6	≤0.17	≤0.18	≤0.05	≤0.05
55/45	≤2.85	3.35-3.80	≤0.13	≤0.15	≤0.03	≤0.03	≤2.90	3.1-4.0	≤0.17	≤0.18	≤0.05	≤0.05
50/50	2.80–3.30		≤0.15		≤0.03		2.70–3.30		≤0.17		≤0.05	

1. Insertion loss over operating wavelength range at ~23°C (excluding PDL and TDL).
2. Insertion loss change over the specified wavelength range.
3. Insertion loss change over the all input polarization states.

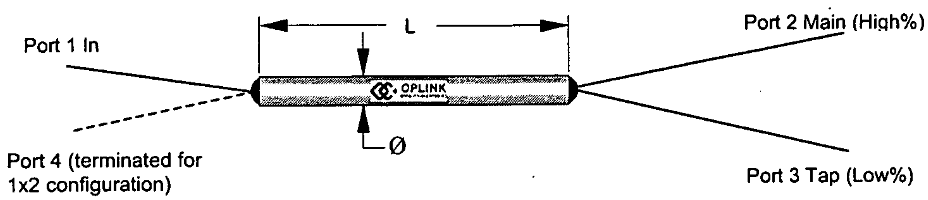
Insertion Loss (IL) II : 1310nm or S band coupler

Coupling Ratio	P Grade						A Grade					
	IL[1] (dB)		WDL[2] (dB)		PDL[3] (dB)		IL[1] (dB)		WDL[2] (dB)		PDL[3] (dB)	
	Signal	Tap	Signal	Tap	Signal	Tap	Signal	Tap	Signal	Tap	Signal	Tap
99/1	≤0.18	18.2-21.0	≤0.05	≤0.90	≤0.03	≤0.03	≤0.23	17.4-21.5	≤0.05	≤1.20	≤0.05	≤0.05
98/2	≤0.25	16.0-18.6	≤0.05	≤0.70	≤0.03	≤0.03	≤0.30	15.2-19.8	≤0.05	≤1.00	≤0.05	≤0.05
97/3	≤0.30	14.4-16.4	≤0.06	≤0.60	≤0.03	≤0.03	≤0.34	13.7-17.1	≤0.07	≤0.90	≤0.05	≤0.05
95/5	≤0.35	12.2-14.0	≤0.08	≤0.50	≤0.03	≤0.03	≤0.40	11.8-14.7	≤0.08	≤0.80	≤0.05	≤0.05
90/10	≤0.60	9.40-11.0	≤0.10	≤0.40	≤0.03	≤0.03	≤0.65	9.00-11.3	≤0.10	≤0.60	≤0.05	≤0.05
85/15	≤0.90	7.70-8.85	≤0.11	≤0.39	≤0.03	≤0.03	≤0.85	7.4-9.1	≤0.12	≤0.67	≤0.05	≤0.05
80/20	≤1.15	6.30-7.80	≤0.11	≤0.37	≤0.03	≤0.03	≤1.15	6.0-8.1	≤0.15	≤0.55	≤0.05	≤0.05
75/25	≤1.50	5.45-6.70	≤0.13	≤0.36	≤0.03	≤0.03	≤1.44	5.5-6.8	≤0.18	≤0.53	≤0.05	≤0.05
70/30	≤1.75	4.60-5.75	≤0.15	≤0.35	≤0.03	≤0.03	≤1.82	4.7-5.9	≤0.20	≤0.50	≤0.05	≤0.05
65/35	≤2.05	4.10-5.05	≤0.17	≤0.33	≤0.03	≤0.03	≤2.02	4.2-5.0	≤0.25	≤0.47	≤0.05	≤0.05
60/40	≤2.50	3.85-4.40	≤0.20	≤0.30	≤0.03	≤0.03	≤2.60	3.7-4.6	≤0.30	≤0.45	≤0.05	≤0.05
55/45	≤2.85	3.15-3.80	≤0.23	≤0.28	≤0.03	≤0.03	≤2.81	3.1-4.0	≤0.35	≤0.42	≤0.05	≤0.05
50/50	2.70–3.40		≤0.25		≤0.03		2.60–3.50		≤0.40		≤0.05	

1. Insertion loss over operating wavelength range at ~23°C (excluding PDL and TDL).
2. Insertion loss change over the specified wavelength range.
3. Insertion loss change over the all input polarization states.

Ultra-Low PDL Fused Tap Coupler (1310, S, C, L band)

Mechanical Footprint Dimension (unit: mm)



Ordering Information

LPTC ☐ ☐ ☐☐ ☐ 0 0 ☐ ☐ ☐ ☐

Wavelength
1310nm=3
C band=5
S band=4
L band=6

Type
1x2=1
2x2=2

Tap Ratio
50/50=50
45/55=45
40/60=40
35/65=35
30/70=30
25/75=25
20/80=20
15/85=15
10/90=10
5/95=05
3/97=03
2/98=02
1/99=01

Grade
P Grade = P
A Grade = A

Package Type
P1 = 1
P2 = 2
P3 = 3

Fiber Type
Corning SMF-28 = 1
900µm Loose Tube = 2
3mm cable = 3

Fiber Length
1.0 meter = 1
1.5 meter = 5
2.0 meter = 2
0.5 Meter = H

Connector Type
None = 1
FC/PC=2
FC/SPC=3
FC/APC=4
SC/PC=5
SC/SPC=6
SC/APC=7
ST=8
LC=9
MU=A

Oplink can provide a remarkable range of customized optical solutions. For detail, please contact Oplink's OEM design team or account manager for your requirements and ordering information (408) 433-0606.

OPLINK COMMUNICATIONS

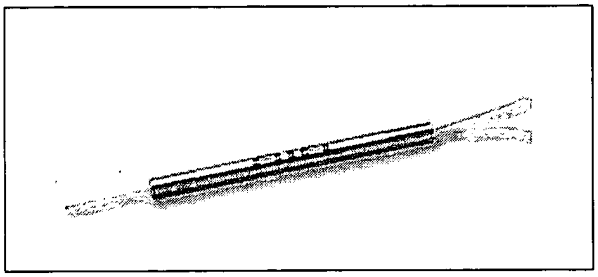
Oplink Communications, Inc.
3469 North First Street San Jose, CA 95134-1803
Tel: (408) 433-0606 Fax: (408) 433-0608
Email: Sales@Oplink.com

Data Sheet
DC202-98 Series
June, 2001

FITEL

980nm Tap Coupler

DC202-98



Applications

- Front Monitoring 980nm pump lasers

Description

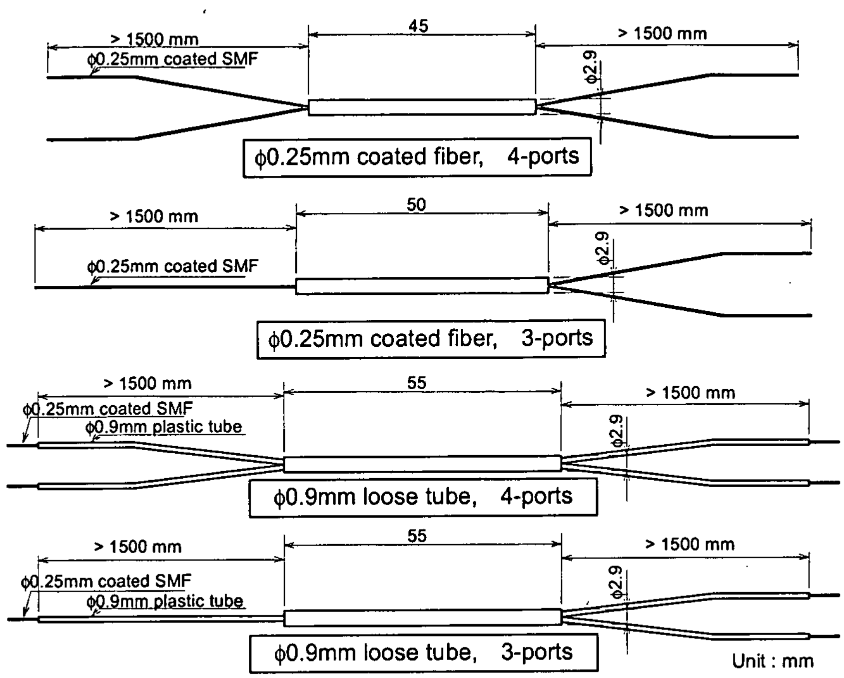
- Small insertion loss fluctuation
- Loose tube pigtails available

Specifications

Parameter		*Specification*
Configuration		1 x 2, 2 x 2
Operating Wavelength		970 ~ 990 nm
Operating Temperature		-10 ~ +70 °C
Storage Temperature		-40 ~ +85 °C
Split Ratio		99:1
Insertion Loss (dB)	Main port	≤ 0.25
	Tap port	19.5 ~ 20.5
Insertion Loss Flatness (dBp-p)	Main port	≤ 0.15
	Tap port	≤ 0.50
Polarization Dependent Loss (dBp-p)	Main port	≤ 0.10
	Tap port	≤ 0.25
Temperature Dependent Loss (dBp-p)	Main port	≤ 0.20
	Tap port	
Fiber		FURUKAWA 980nm single-mode fiber
Size	ϕ0.25mm fiber type	2x2type;ϕ2.9 x L45mm, 1x2type;ϕ2.9 x L50mm
	ϕ0.9mm loose tube type	2x2type;ϕ2.9 x L55mm, 1x2type;ϕ2.9 x L55mm

All specifications not include connectors.
Available for FC-SPC, SC-SPC connectors for each port.

Dimensions



Ordering Information

DC202 – 98 – 01 – [ ] – [ ] – [ ]

Split Ratio	
Symbol	
50	50:50
10	90:10
05	95:5
02	98:2

Pigtail	
Symbol	
A	φ0.25mm Coated
B	φ0.9mm Loose Tube

Configuration	
Symbol	
3	3 ports
4	4 ports

Headquarters
6-1 Marunouchi 2-chome
Chiyoda-ku Tokyo
100-8322 Japan
T: 81-3-3286-3141
F: 81-3-3286-3515
www.furukawa.co.jp

Furukawa Electric Europe, Ltd
3rd FL Newcombe House
43-45 Notting Hill Gate
London, UK
T: 44-171-221-6000
F: 44-171-313-5310
www.furukawa-fitel.c .uk
sal s@furukawa-fit l.c .uk

Perryville Corporate Park
Perryville III
Clinton, NJ 08809
USA
T: 908-713-3525
F: 908-713-3515
www.fiteltech.c m
sales@fit ltech.c m

OPTIMIZATION OF TAP COUPLERS MADE BY THE FBT PROCESS

D. R. Moore, Z. X. Jiang, and V. J. Tekippe
Gould Fiber Optics, 1121 Benfield Blvd.
Millersville, MD, USA 21108

ABSTRACT

Tap couplers with small coupling ratios (1-10%) play a critical role in monitoring optical fiber systems such as optical amplifiers. They are often used in a feedback control loop and hence must exhibit extreme stability. Very small changes in the operating characteristics of the taps can be interpreted as changes in laser power giving rise to instability in the amplifier gain.

Tap couplers made by the fused biconical taper (FBT) process are inherently stable with regard to temperature and, thus, this is usually not a concern. Of much greater significance are the wavelength dependence and polarization sensitivity of the tap ratio. Wavelength dependence can be minimized by introducing a mismatch in the propagation constants between the two fibers, but it is also influenced to a lesser extent by the coalescence of the fibers. On the other hand, polarization sensitivity is primarily dependent on coalescence and only somewhat dependent on propagation constant mismatch. As a consequence, it is necessary, in practice, to trade off wavelength dependence against polarization sensitivity in order to optimize the overall stability of the tap coupler. We report here the results of such an optimization study, consistently yielding taps with less than 0.5 dB total change in the insertion loss of the tap leg due to all effects.

INTRODUCTION

In just a few short years the optical amplifier has become an essential part of most modern telecommunication systems. This ubiquitous quality is due to its ability to amplify light directly over a fairly broad wavelength range. As a result, optical amplifiers are used in terrestrial and undersea applications for both single and multi-wavelength systems. Since the amplification of the data signal occurs only in the optical domain, it is of paramount importance that these amplifiers exhibit excellent gain stability. Even very small changes in amplifier gain can have serious consequences in cascaded amplifier systems. Consequently, pro-active means are usually taken to ensure stability of the amplifier. Figure 1, for example, shows a schematic diagram of a generic single pump erbium doped optical fiber amplifier. In operation, the optical energy from the pump laser enters the erbium doped fiber via the wavelength division multiplexer (WDM) and raises the erbium atoms to

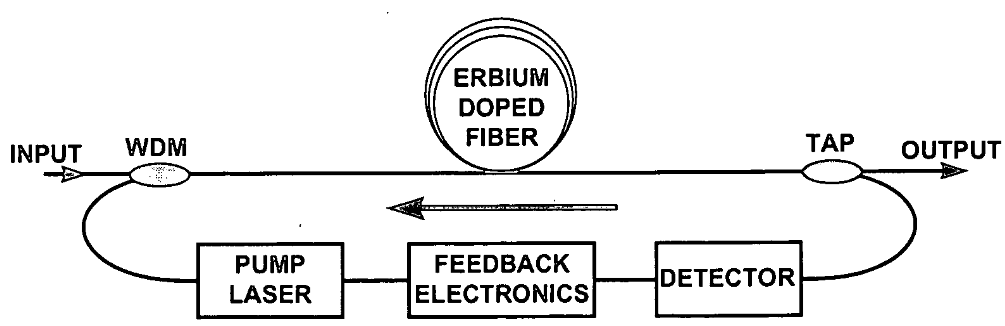


Figure 1. Schematic diagram of single pumped erbium doped optical fiber amplifier.

an excited state such that when the input signal passes through the doped fiber it becomes amplified by stimulated emission of the erbium atoms. The component labeled "tap" plays a key role in the stability of the amplifier because, as it's name implies,

it taps off a small amount (usually 1% to 10%) of the amplified signal as a feedback signal to the pump drive electronics. Such tap components must exhibit extreme stability themselves if they are going to perform reliably in the feedback loop. Any instability in this component can be misinterpreted by the feedback electronics as instability in the amplifier gain .

Tap components made by the fused biconical taper (FBT) process are particularly well suited for this application since the are inherently stable with regard to temperature and can carry the high optical power levels common in modern optical amplifier systems. Such taps, however, must also be stable with respect to both the wavelength and polarization state of the light. Obtaining these attributes are not necessarily straightforward since one must often make trade-offs between them. For example, wavelength dependence is primarily determined by a mismatch in the propagation constants while polarization sensitivity is mostly related to coalescence of the fused fibers. At the same time, however, wavelength dependence can also be influenced by coalescence and polarization sensitivity is somewhat related to the propagation constant mismatch. Obtaining optimal stability for FBT taps by trading off these parameters is the subject of this paper.

THEORETICAL CONSIDERATIONS

For simplicity , the discussion of tap stability will be confined to the major parameters affecting FBT taps, *viz.*, polarization, wavelength, and temperature. Other tap technologies may have different stability considerations. Figure 2 shows how each of the above factors can contribute to variations in the insertion loss of the tap , and hence, to its stability. The nominal insertion loss is primarily due to the splitting loss of the tap. Only a very small contribution (< 0.1 dB) is due to the excess

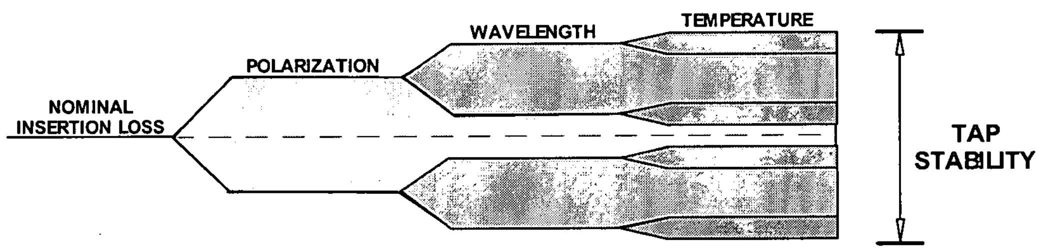


Figure 2. Polarization, wavelength, and temperature contributions to tap stability.

loss of the FBT process. Each of the other factors can contribute both positively and negatively to the nominal insertion loss because they affect the coupling ratio of the tap. Since each factor can contribute independently, the worse case tap stability, as shown in Fig. 2, must be considered. In practice, however, the various contributions often off-set each other, resulting in variations which are less than the worse case value.

Since fused couplers are made at about 1500°C by actually heating and fusing two or more fibers together, their properties are locked into the resulting glass structure. This, in conjunction with the stability of the glass itself and Gould's patented GlasSolder™ packaging technology (1), enables FBT couplers to exhibit excellent thermal stability. Typical variations in the insertion loss of the tap leg are about 0.1dB over an operating temperature range of 0-70°C.

The wavelength dependence of the tap ratio can be reduced by introducing a mismatch between the propagation constants of the two fibers (2). This can be accomplished, for example, by pre-tapering one of the fibers, by etching one of the fibers, or by changing the index of refraction of one of the fibers. The mismatch between the propagation constants causes incomplete coupling between the two fibers and results in a broad sin squared coupling that peaks at a value less than 100%. The peak of the coupling ratio curve can be selected by adjusting the amount of mismatch between the two fibers. A so-called wavelength flattened tap coupler can be made in this manner such that the variation in the insertion loss of the tap leg is less than 0.2 dB over the useable gain region of an erbium doped optical amplifier (1530-1565nm).

The polarization dependent loss is most strongly influenced by the degree of coalescence of the two fibers during the fusion process (3). This is because the polarization dependent loss arises from the structural asymmetry that is inherent to the FBT process. With essentially two fibers lying side by side, the electric field of a light wave traveling in one of the fibers will "see" a different view if it is aligned along the center-line of the two fibers rather than perpendicular to it. This birefringence gives rise to slightly different values of coupling ratio for these two orthogonal states of polarization. This, in turn, gives rise to small variations in the coupling as the plane of polarization of the incident light is rotated. This sensitivity to polarization can be reduced by increasing the coalescence of the fibers during the fusion process so that a more symmetric structure is obtained. Contrary to what one might believe, the optimum condition for minimizing the polarization effect does not occur when the two

fibers are completely fused into a circular structure but rather somewhere between full coalescence and no coalescence (3). In practice one usually has to determine this optimum point experimentally since it also depends on other factors, including the type of fiber and the type of component.

To complicate matters further, the wavelength dependence of the tap coupler also depends, to a lesser extent, on the coalescence of the fused fibers. Similarly, the polarization dependent loss is also influenced by the mismatch between the propagation constants. As a result the optimum condition for minimizing both of these effects must be determined empirically and usually requires a compromise between the optimum conditions for each effect by itself. The results of such an optimization study for tap couplers is given in the next section.

EXPERIMENTAL RESULTS

In order to determine the optimum fabrication parameters to minimize tap instability, a series of measurements were performed on FBT tap couplers made under various conditions. Mismatches between the propagation constants of the fibers were created by pre-tapering one of the fibers prior to forming the coupler. For a number of different pull speeds, the polarization dependent loss of the tap leg was measured for a series of different fiber diameter ratios. The fiber diameter ratio determines the mismatch between the propagation constants and the pull speed is inversely proportional to the coalescence of the fibers. The experimental data for 4% taps is shown in Figure 3. This data clearly shows that there is an optimum fiber diameter ratio or propagation constant mismatch at which the polarization dependent loss is a minimum,

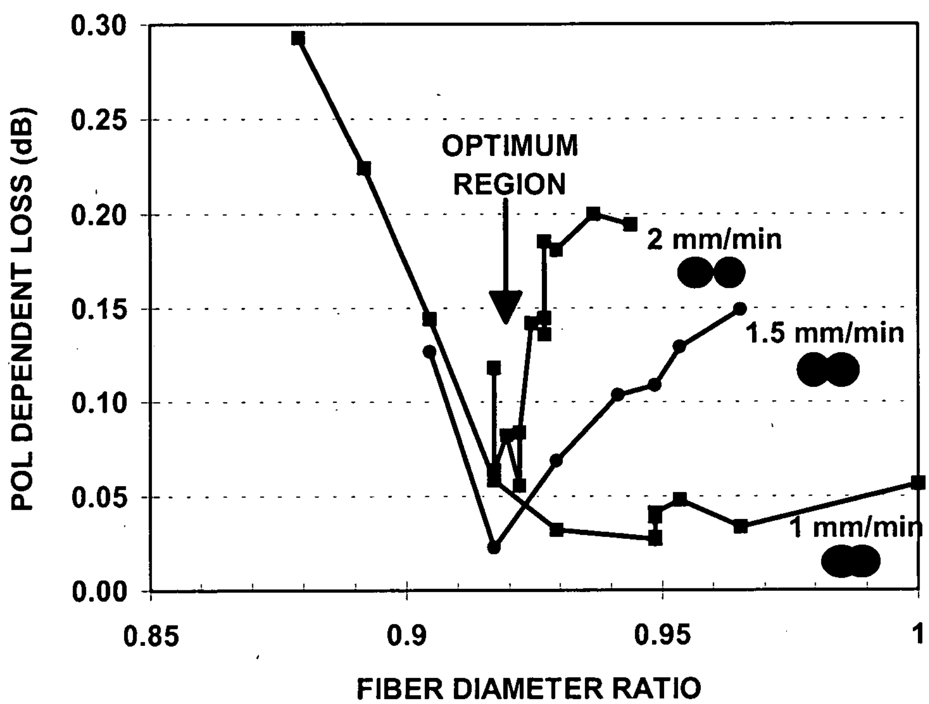


Figure 3. Empirical determination of optimum fabrication parameters for 4% taps.

essentially independent of the degree of coalescence or pull speed. While there is no obvious theoretical justification for this occurrence, it is fortuitous for the fabrication of FBT tap couplers.

Although the fiber diameter ratio of 0.92 exhibited the lowest polarization dependent loss for the 4% tap couplers, it does not automatically provide the optimum mismatch in propagation constants that minimizes wavelength dependence. In fact, the peak coupling ratio associated with this fiber diameter ratio is slightly higher than 4%. Therefore, when fabricating a 4% tap, the process must be terminated before the coupler ratio reaches its maximum coupling ratio, resulting in a less than optimum condition for wavelength dependence. As shown in Figure 4, the insertion loss of the 4% leg slowly decreases with increasing wavelength because the peak coupling ratio of the tap coupler occurs at higher wavelengths. In the ideal case, the peak coupling ratio would occur at about 1550 nm, the center of the useful gain curve of the erbium amplifier. Despite this less than optimum result, the change in the insertion loss of the 4% leg is less than 0.25 dB over the wavelength region of 1530 - 1565 nm.

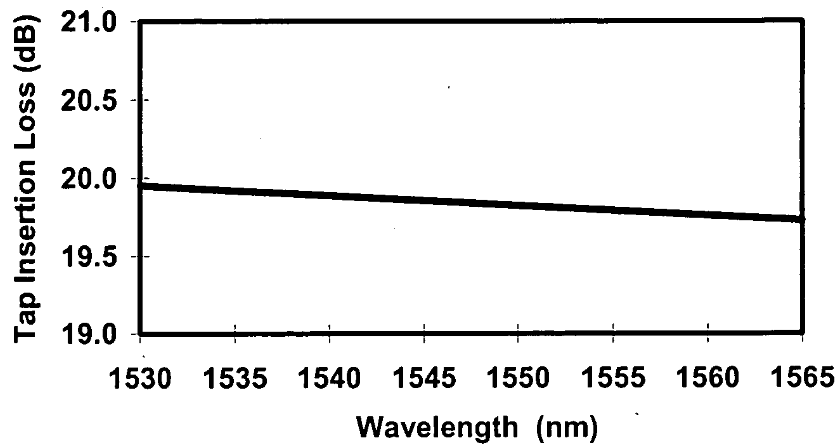


Figure 4. Wavelength dependence of 4% tap made with minimum polarization dependent loss.

To illustrate the use of the optimization process discussed above, a group of 1% taps were made by the FBT process. The frequency distribution and cumulative percent for the overall stability of the tap leg is shown in Figure 5 for 122 units. The tap stability includes the effects due to temperature over the range of 0-70°C, wavelength dependence from 1530-1565nm,

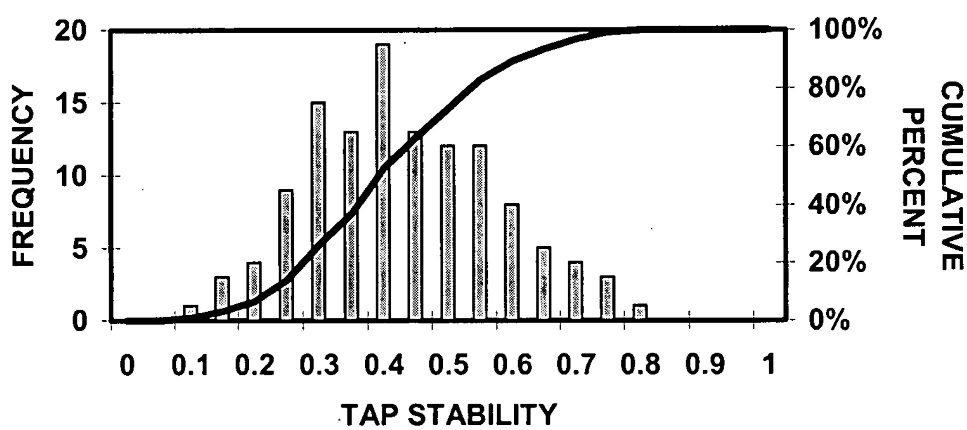


Figure 5. Frequency distribution of 1% taps optimized for maximum tap stability

and polarization dependent loss. The peak of the distribution occurs at an overall stability of about 0.4 dB for the 1% leg. Furthermore, more than 75% of the product exhibits less than 0.5 dB variation in insertion loss due to all effects.

CONCLUSION

In this paper we have shown that tap couplers made by the FBT process can meet the stringent stability requirements of optical fiber amplifiers. Temperature effects are minimized by using Gould's patented GlasSolder™ technology to secure the coupler to a supporting substrate. Minimizing the polarization dependent loss of the tap is achieved by optimizing the coalescence of the coupler. The wavelength dependence of the coupler is also reduced by using a mismatch in the propagation constants of the fibers that, at the same time, minimizes the polarization dependent loss. When these optimization techniques were used to fabricate 1% FBT tap couplers, more than 75% of the units exhibited an overall stability for the 1% tap leg of less than 0.5 dB.

REFERENCES

(1) *A Glass Solder Process for Packaging Fiber Optic Components*, H. S. Daniel, D. R. Moore, and V. J. Tekippe, Proceedings of NFOEC '94, San Diego, California (1994) and Proceedings of EFOC&N, Heidelberg, Germany, (1994).

(2) *Passive Fiber Optic Components Made by the Fused Biconical Taper Process*, Fifth National Symposium on Optical Fibers and Their Application, Warsaw, SPIE, 1085, (1989). Reprinted in Fiber and Integrated Optics, 9, 97-123, (1990).

(3) *Finite Element Analysis for Fused Couplers*, X. H. Zheng, Electron. Lett., 22, 804-805, (1986).